Understanding Ecosystem Productivity and Predicting Population Resilience Via Steepness

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NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
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ECOSYSTEM-BASED MANAGEMENT OF FISHERIES IN THE U.S. PACIFIC ISLANDS

Western and Central Pacific Fisheries Commission

International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

Overview

- BACKGROUND
- EXAMPLE: NORTH PACIFIC STRIPED MARLIN
- CONCLUSIONS AND FUTURE RESEARCH

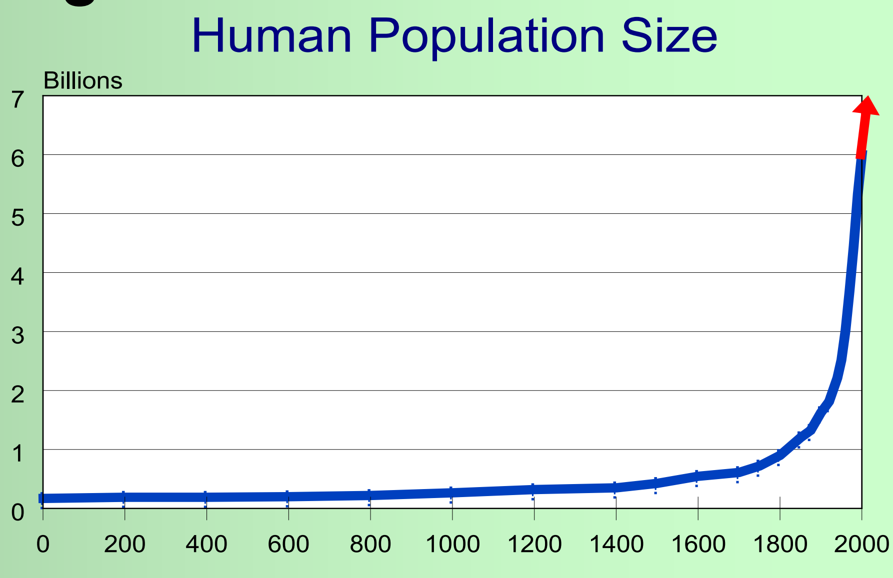
An Ecosystem Approach to Management

• Monitor ecological indicators of ecosystem status

• Assess status of fisheries resources

• Provide forecasts for fisheries resources and for the marine ecosystem

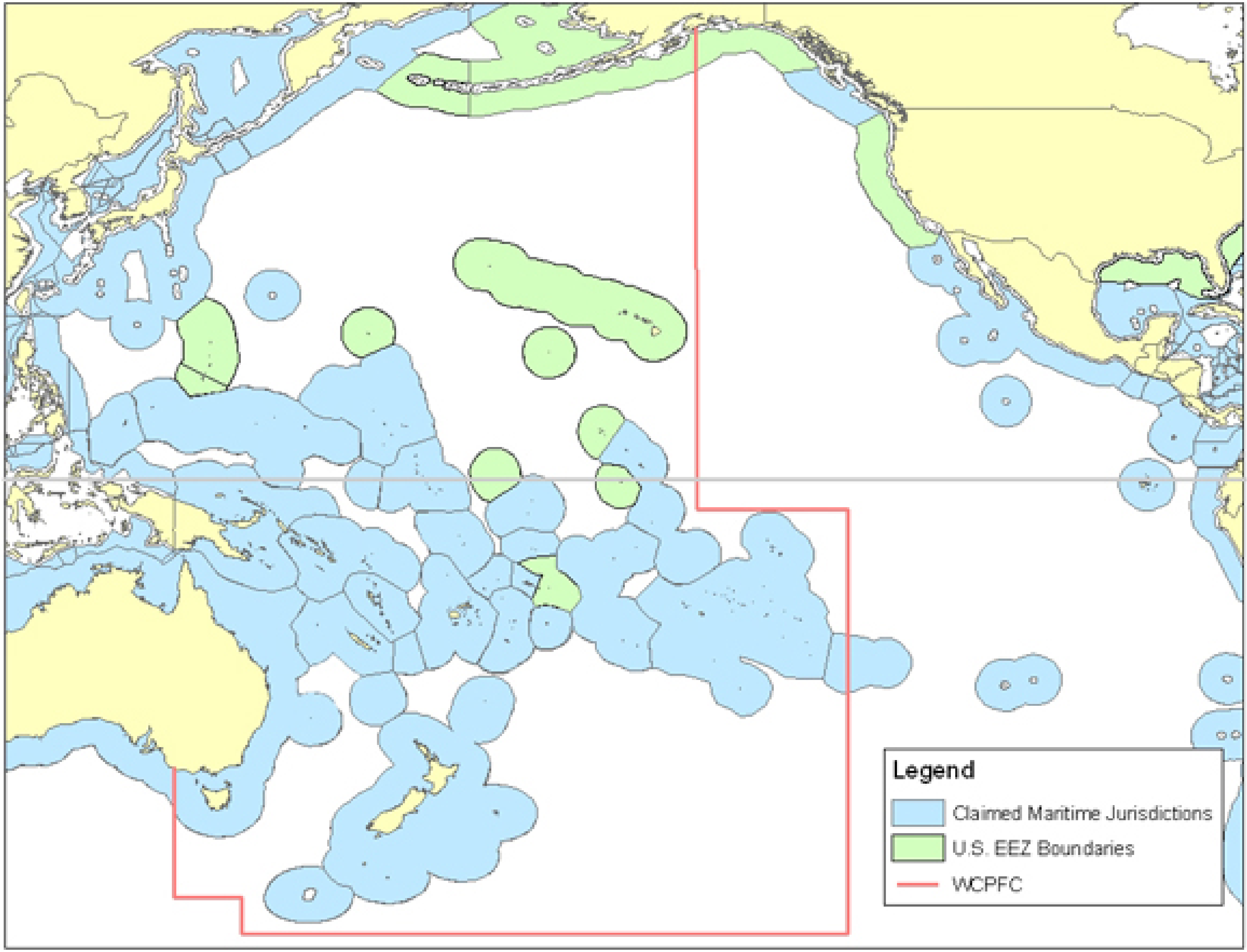
- **What are the effects of fishing ?**
- **What are the impacts of environmental change ?**



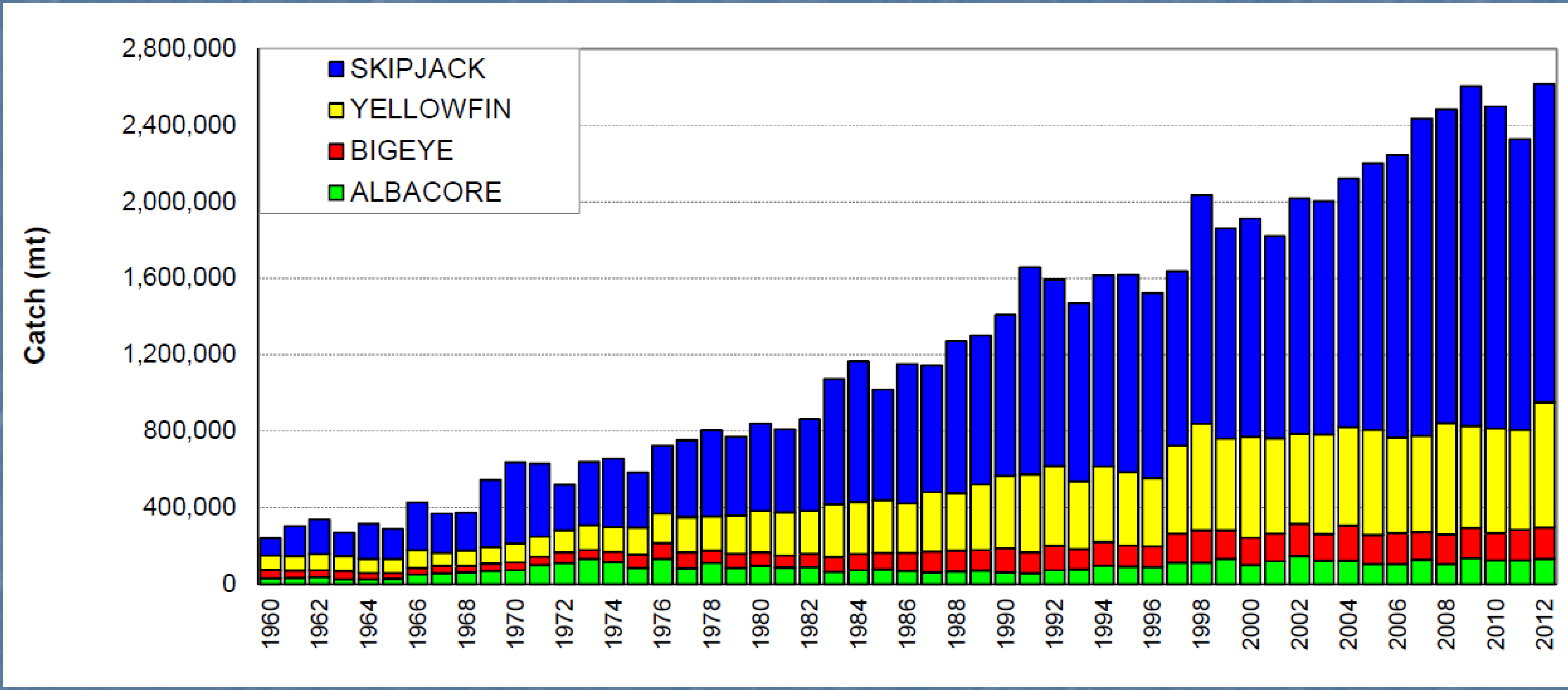
Data from Kremer (1993) and U.N. (2000)

Brodziak, J. and Link, J. 2002. Ecosystem-based fisheries management: What is it and how can we do it? Bulletin of Marine Science 70(2):589-611.

Western and Central Pacific Fisheries Commission



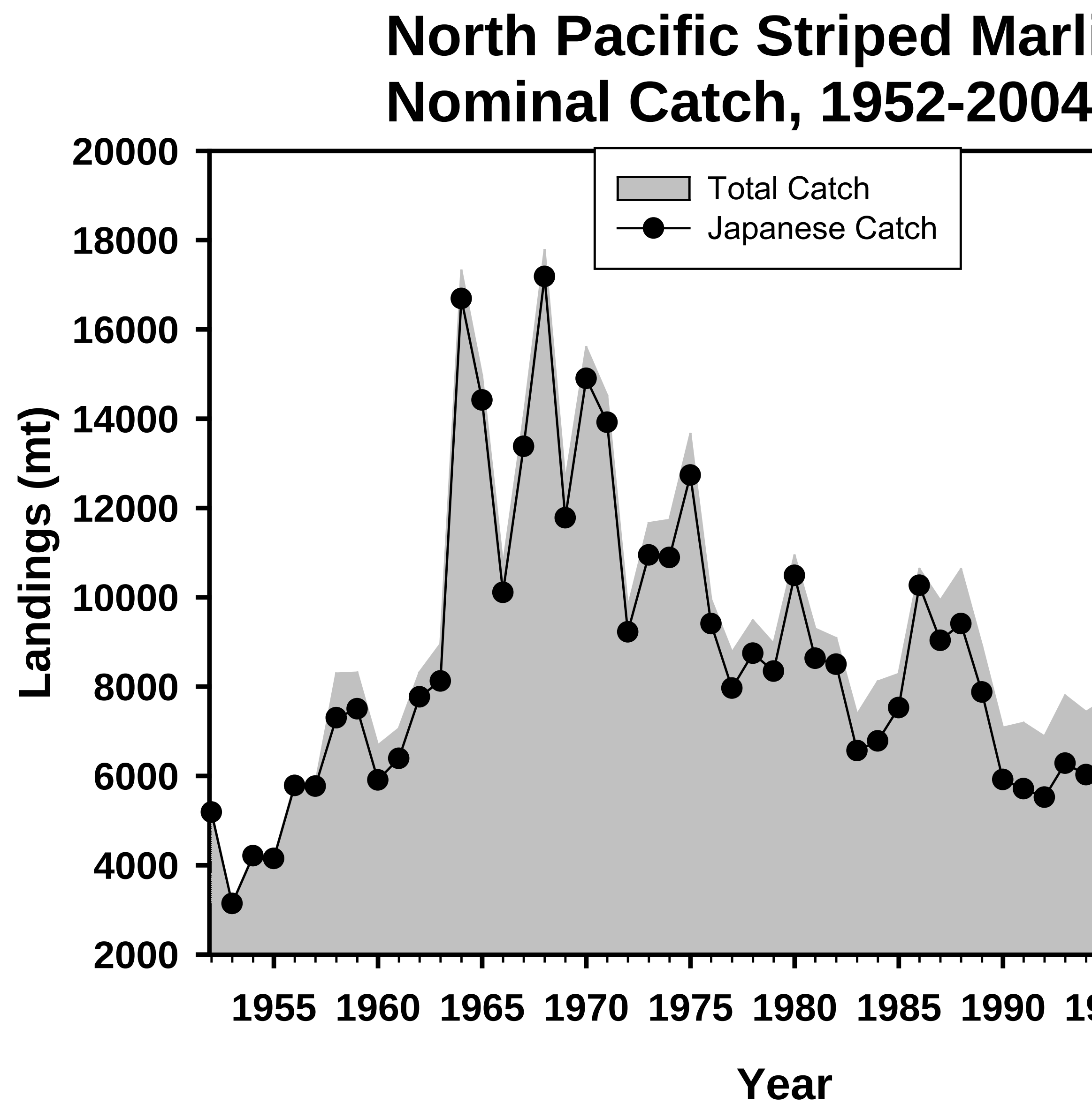
Western and Central Pacific Pelagic Fisheries: Trends in Catch by Species



Probably all the great sea fisheries are inexhaustible" ~ Thomas Huxley 1884

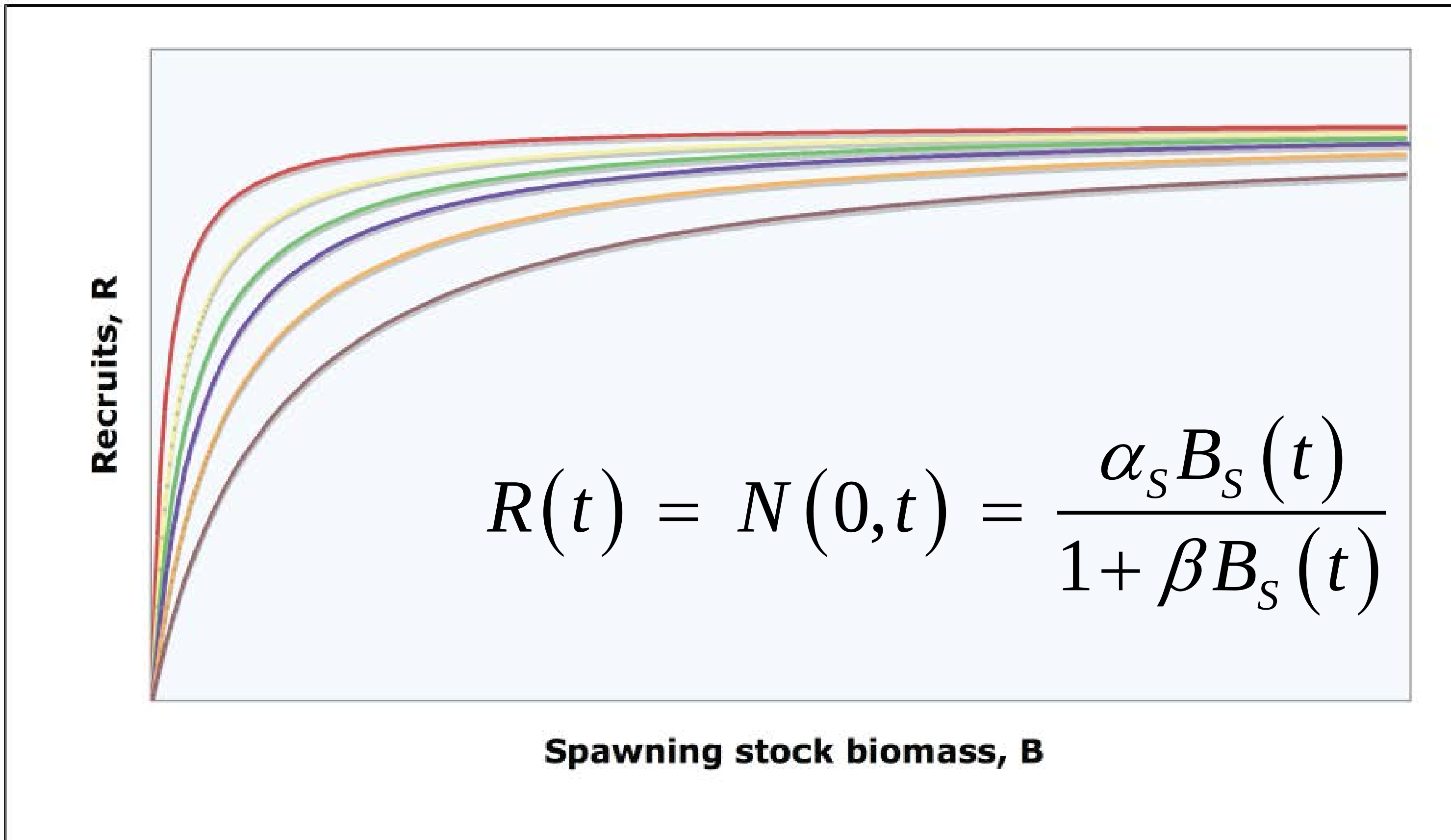
"It is a mistake to suppose that the whole ocean is practically one vast store house"
~ Ray Lankester 1884

North Pacific Striped Marlin Assessment in 2007: A One-Way Trip



Classical Approach to Density-Dependent Recruitment

$$R = f(B)$$

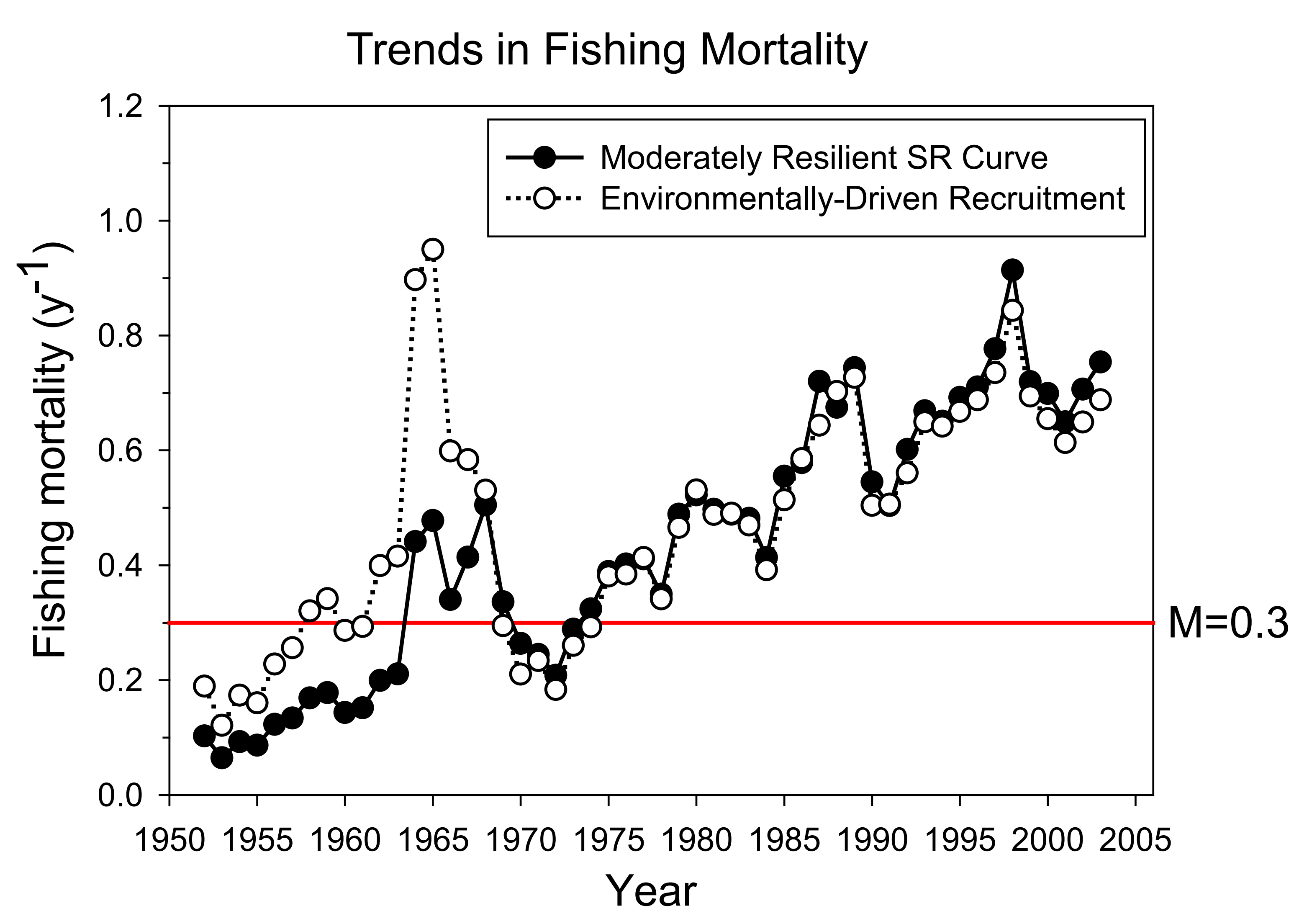


$$R(t) = N(0,t) = \frac{\alpha_S B_S(t)}{1+\beta B_S(t)}$$

$B_S(t)$ *is mature female biomass at time t*

Uncertainty About Resilience

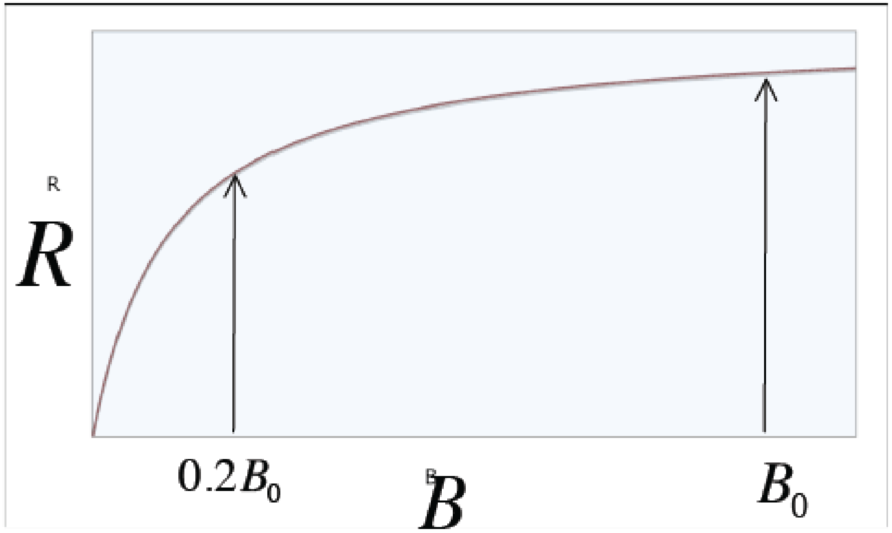
- **Recruitment dynamics modeled using 2 hypotheses**
  - **Mean recruitment follows a Beverton Holt SR curve, *h*=0.7**
  - **Environmentally-driven recruitment about mean, *h*=1**



What is Steepness: Mace and Doonan (1988)

Steepness: Fraction of the recruitment at the unfished the spawning biomass when the spawning biomass is 20% of the unfished size

$$h = \frac{R(0.2B_0)}{R(B_0)}$$



Mace, P. and I.J. Doonan. 1988. A Generalised Bioeconomic Simulation Model for Fish Population Dynamics. New Zealand Fishery Assessment Research Document 88/4, Fisheries Research Centre, MAFFish, POB 297, Wellington, NZ.

Calculating a Prior Distribution for Steepness

Apply Standard Age-Structured Population Dynamics Model For An Unfished Stock With

- Density-Independent Growth, Maturity, Fecundity
- Beverton-Holt Recruitment Dynamics
- Allometric Scaling of Natural Mortality

Expected female spawning biomass per recruit

$$SPR_f = \sum_{a=1}^{A_{MAX}} S(a) \cdot W_f(a) \cdot p_{f,m}(a)$$

Steepness as a Function of Slope at the Origin

Simplify the expression for steepness (h) using lifetime expected female spawning biomass per recruit and Beverton-Holt assumption gives

$$h = \frac{\alpha_S \cdot SPR_f}{4 + \alpha_S \cdot SPR_f}$$

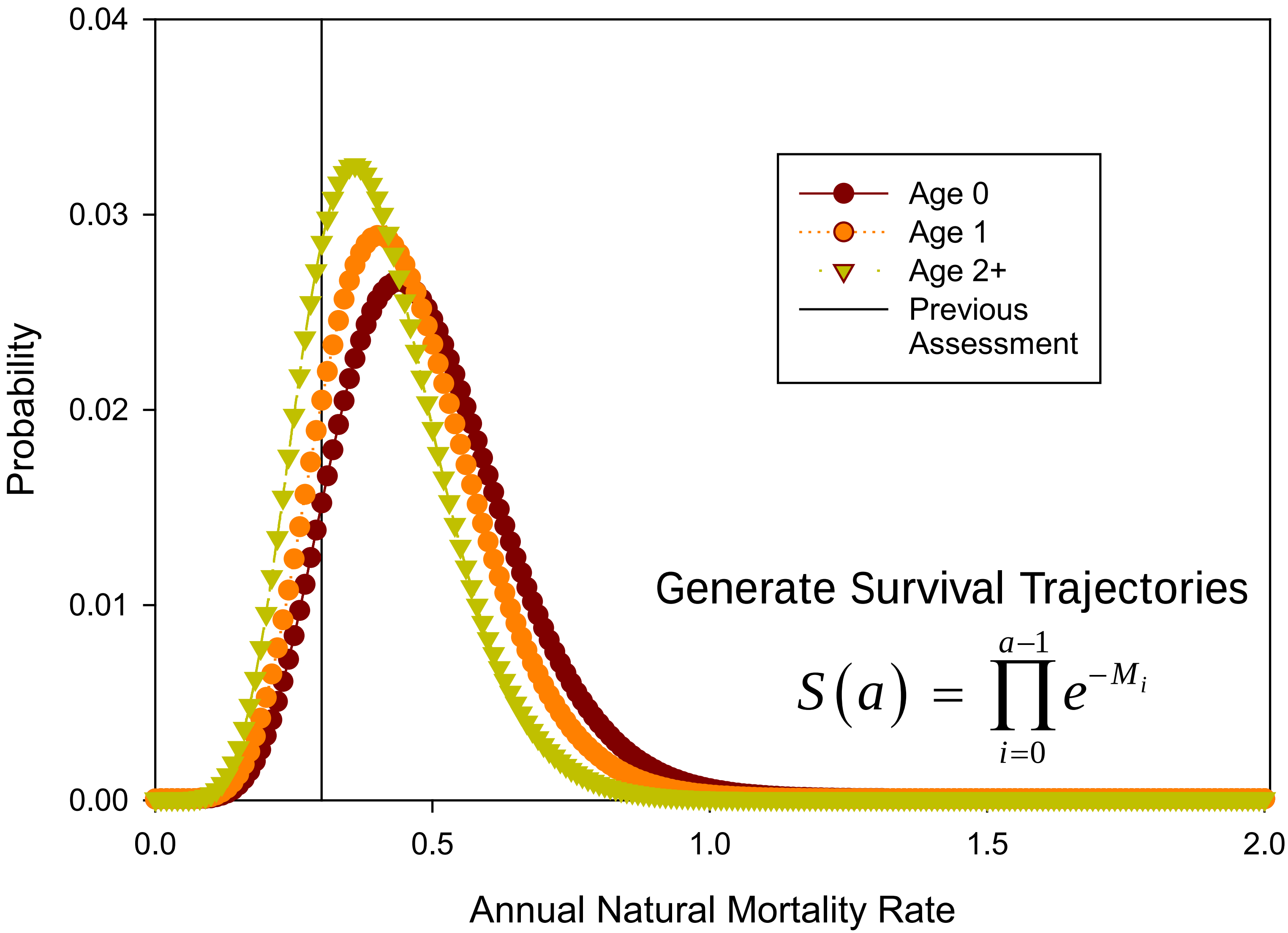
Monte Carlo Simulation to Construct Steepness Distribution

Randomly sample age distribution of subpopulation k $\{A_{n,k}\}$ with fish mass $W(A_{n,k})$, fecundity $F(W)$, early life history survival rate $S(A_{n,k})$, and mean number of batches of eggs n_B to estimate slope at origin

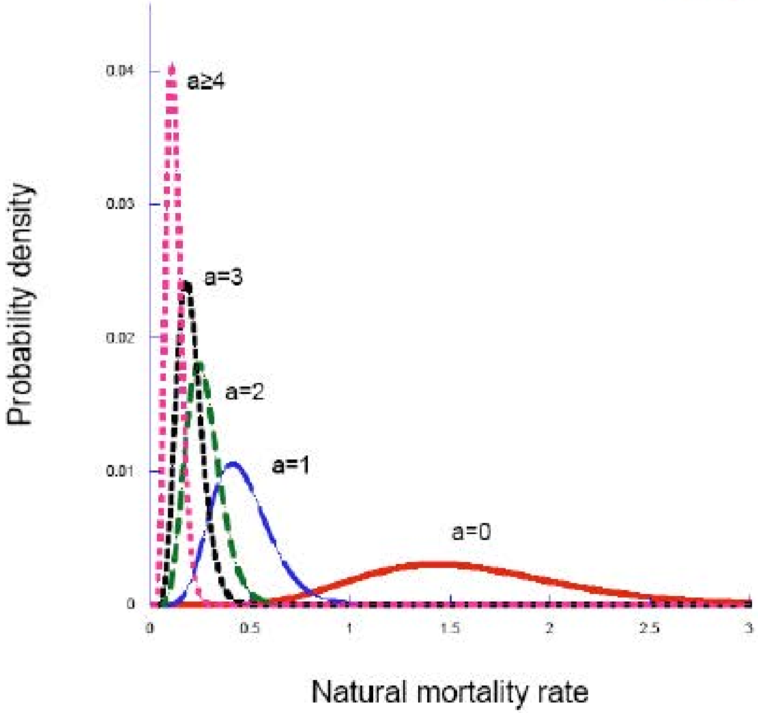
$$\alpha_S(k) = \frac{\sum_n S\left(A_{n,k}\right) F\left(W\left(A_{n,k}\right)\right) \cdot n_B}{\sum_n W\left(A_{n,k}\right)}$$

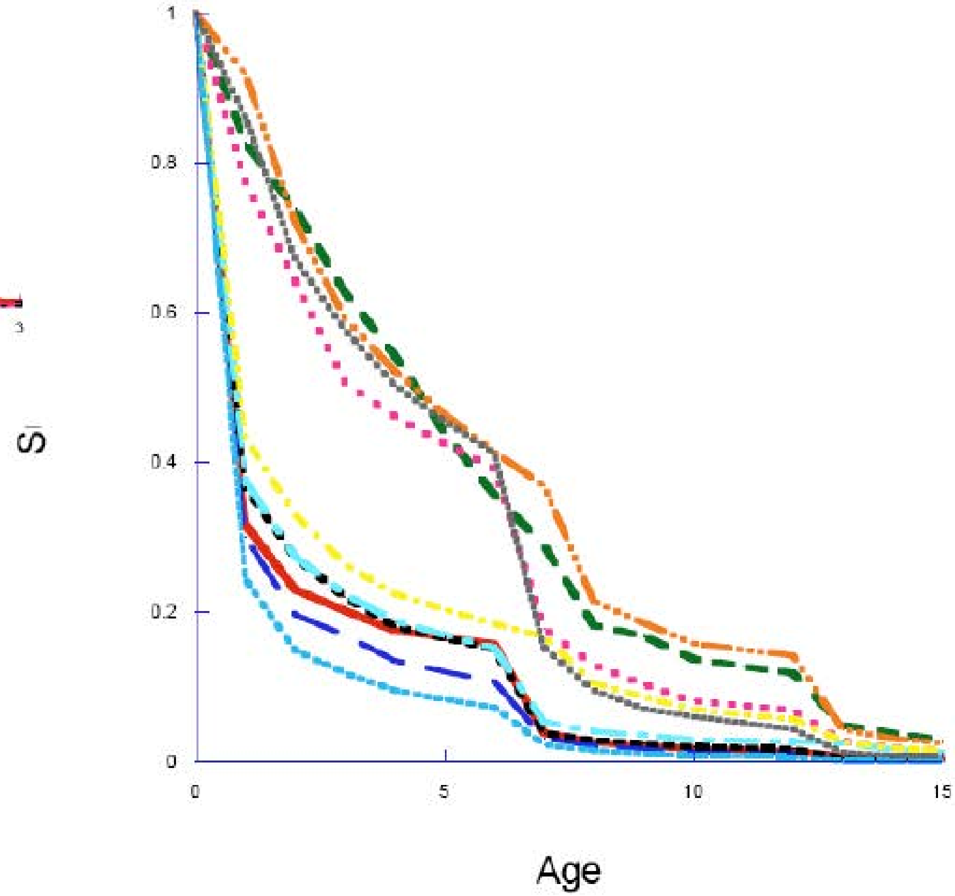
$$CV(\theta) = 10\%$$

Striped Marlin Adult Natural Mortality

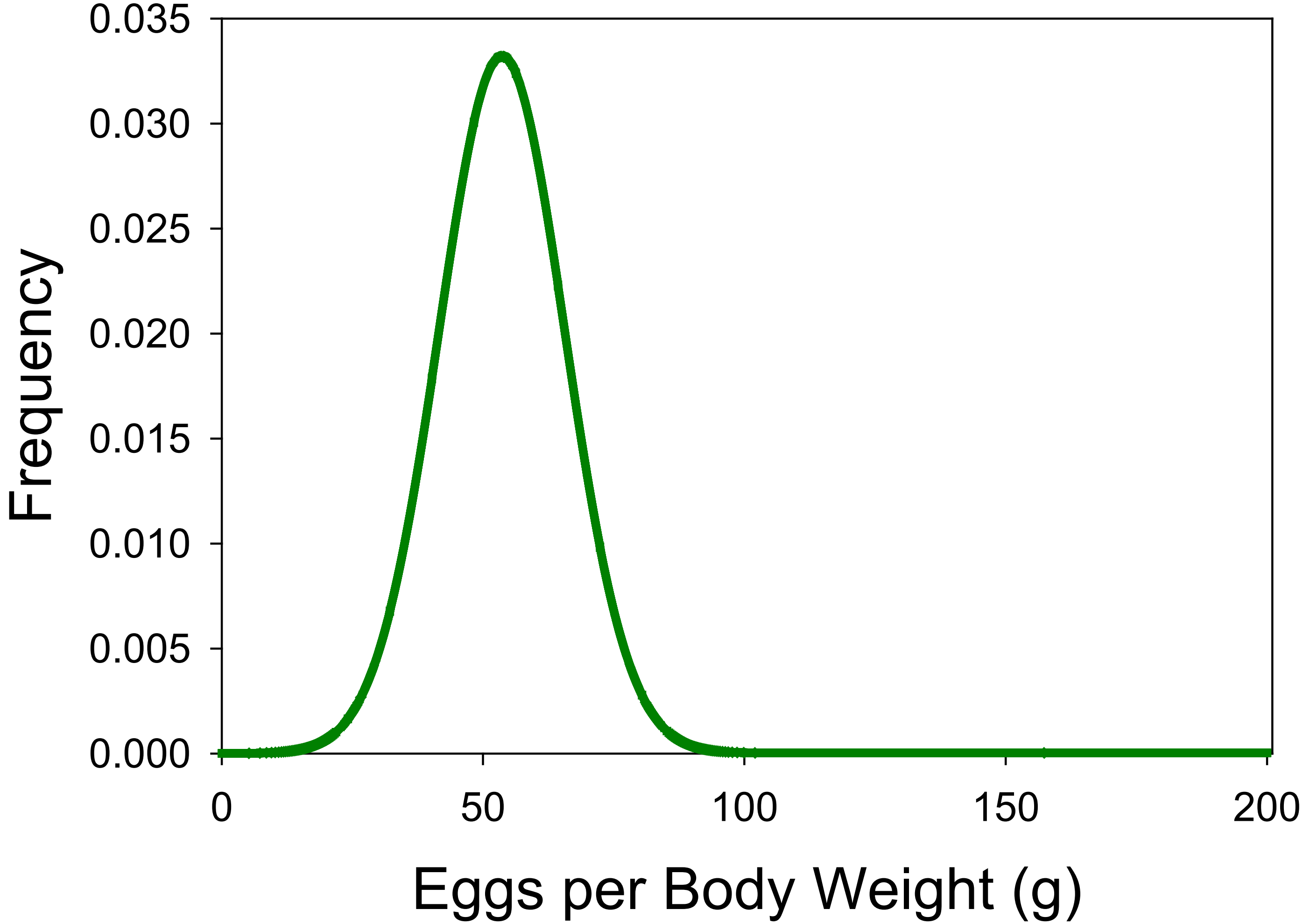


Survival Trajectories With Uncertainty in Age Dependent Mortality

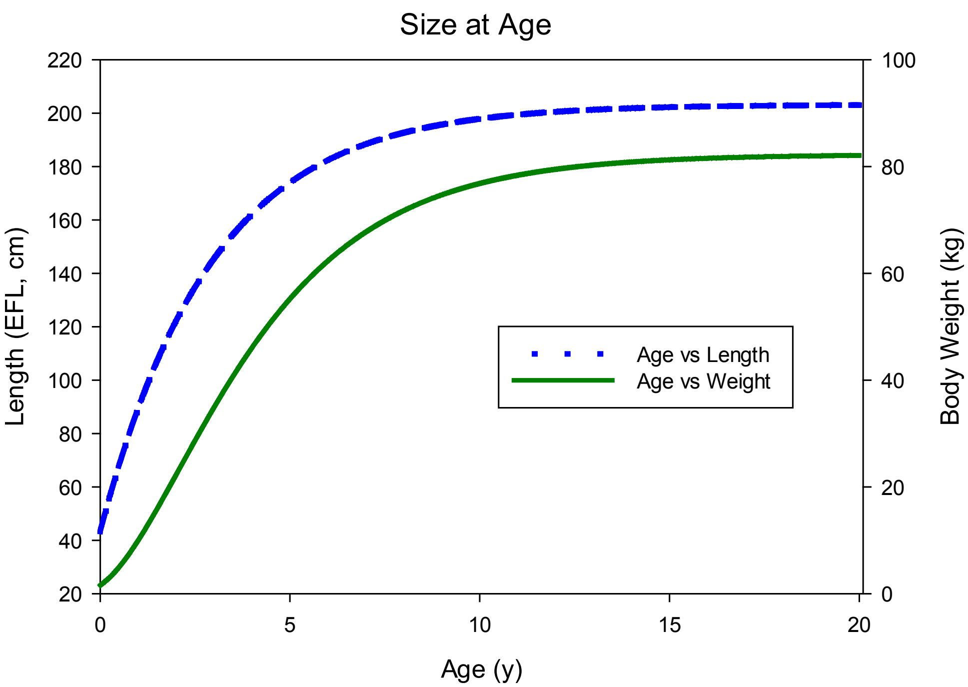


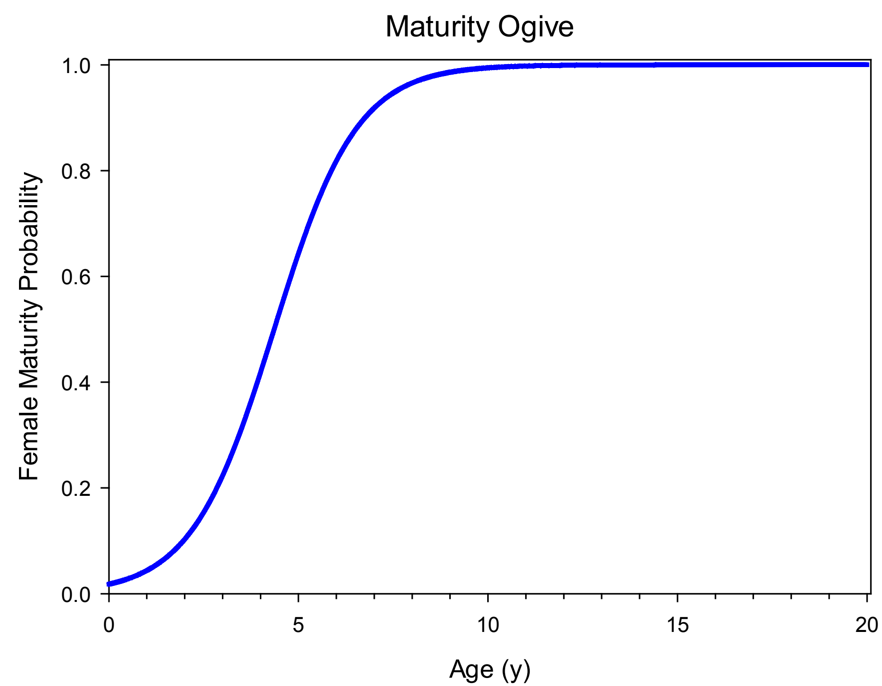


Striped Marlin Relative Fecundity



Striped Marlin Life History Parameters: Adult Size and Maturity at Age

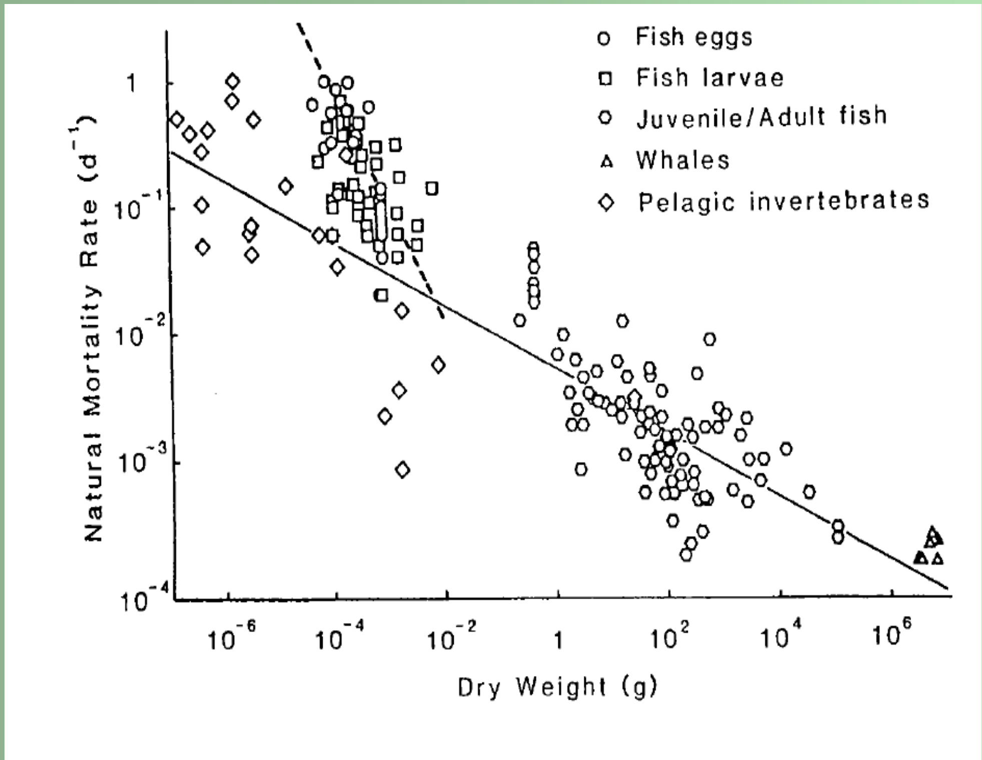




Modeling Steepness

Binding Limitations

- **Estimation Using Life History Parameters**
- **Larval Survival** $S_l(d) = S_l(d-1) \cdot \exp(-M_l(w_d))$



$$\frac{\partial \beta}{\partial t} + W \frac{\partial(\beta W)}{\partial t} + \beta M = 0$$

McGurk, M.D. 1986. Natural mortality of marine pelagic fish eggs and larvae: the role of spatial patchiness. Marine Ecology Progress Series 34:227-242

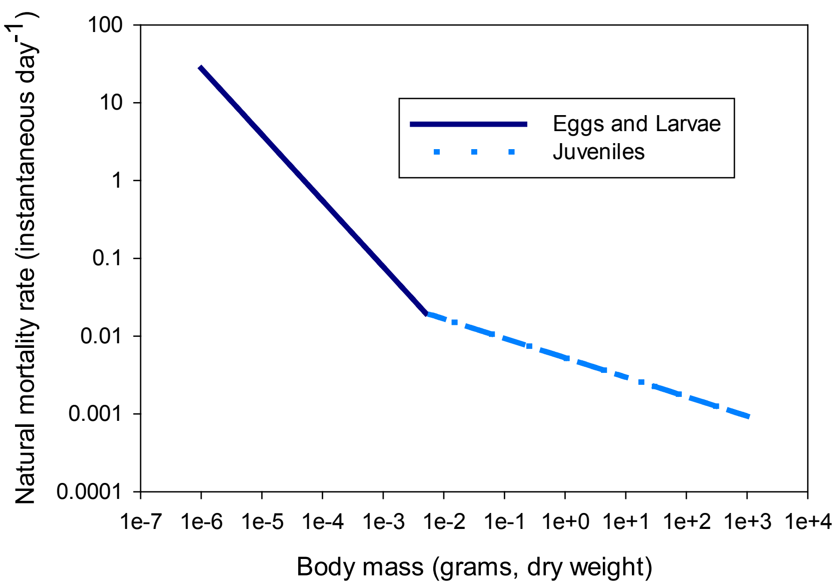
Early Life History Stage Survival and Growth

ELH weight (W) by day (d)

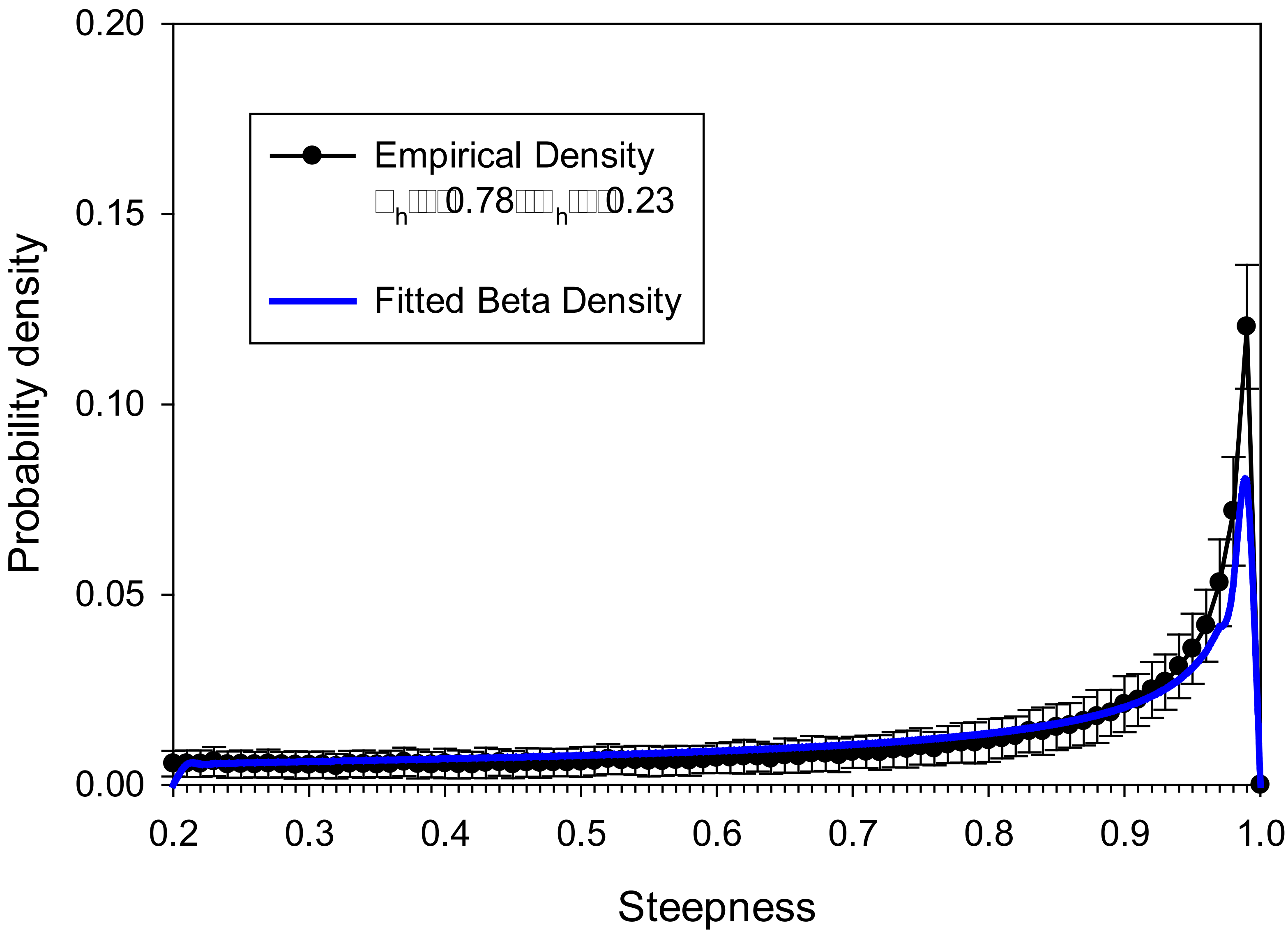
$$W_{ELH}(d) = W_{Egg} \cdot \exp\left(k_{ELH} \cdot d\right)$$

ELH survival (S) to day (d)

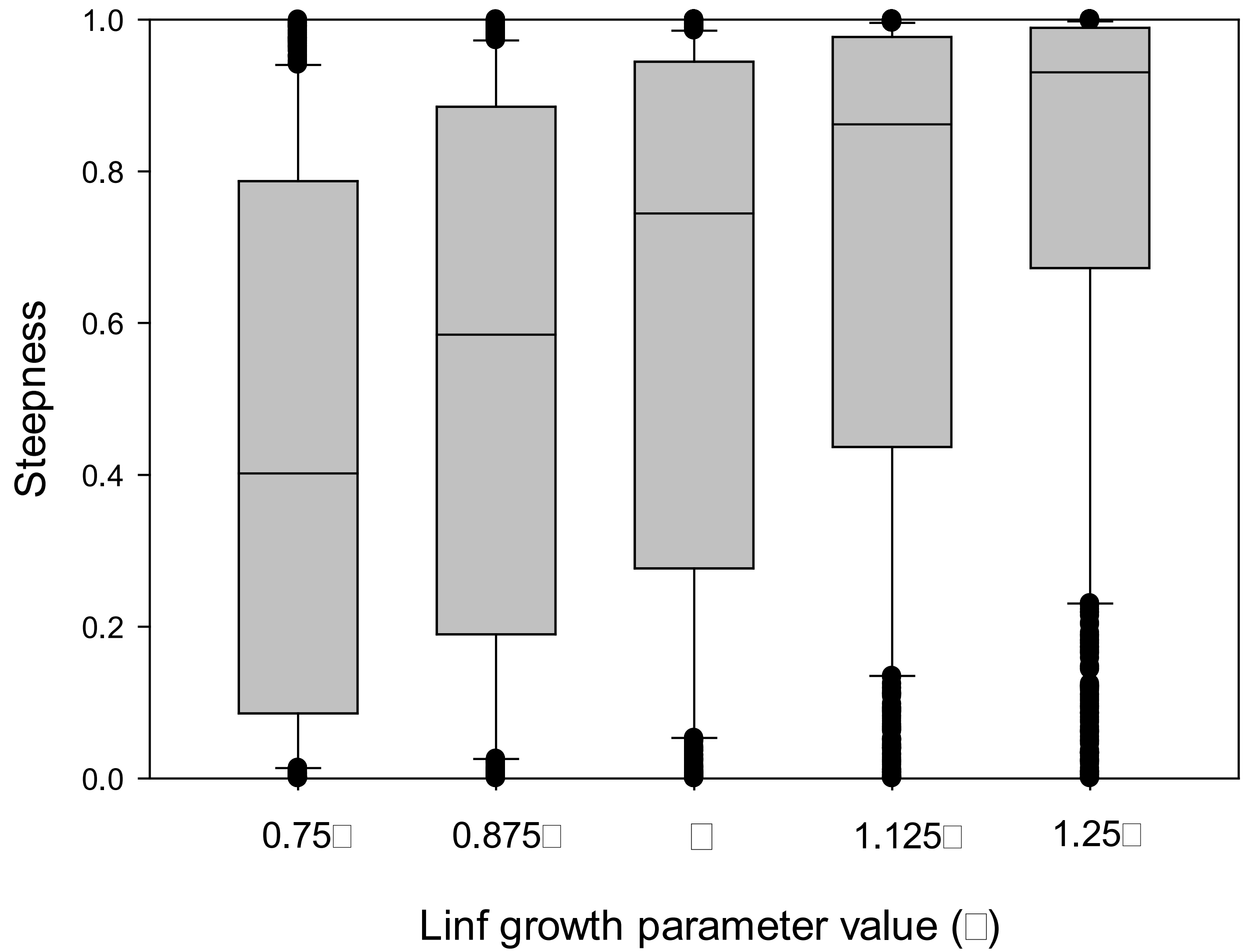
$$S_{ELH}(d) = S_{ELH}(d-1) \cdot \exp\Big(-M\big(W_{ELH}(d)\big)\Big)$$



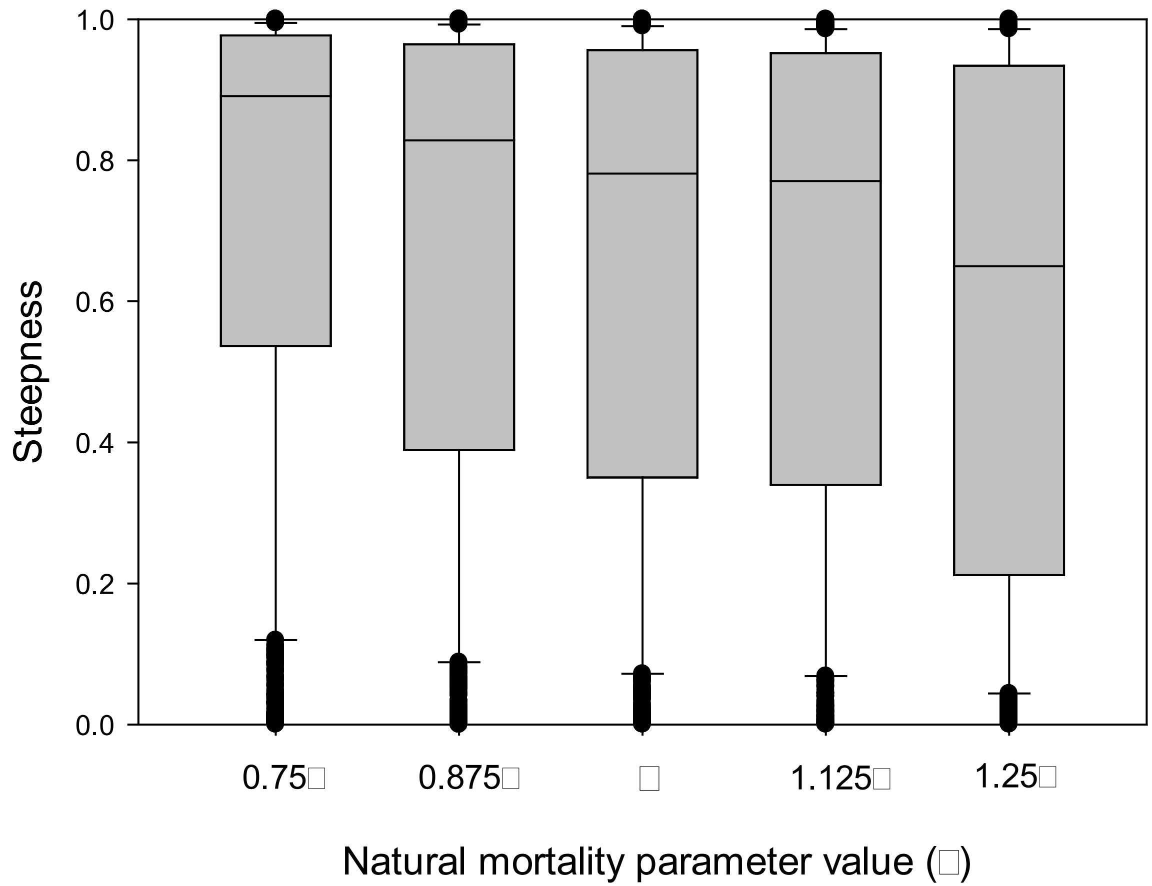
Striped Marlin Steepness Distribution



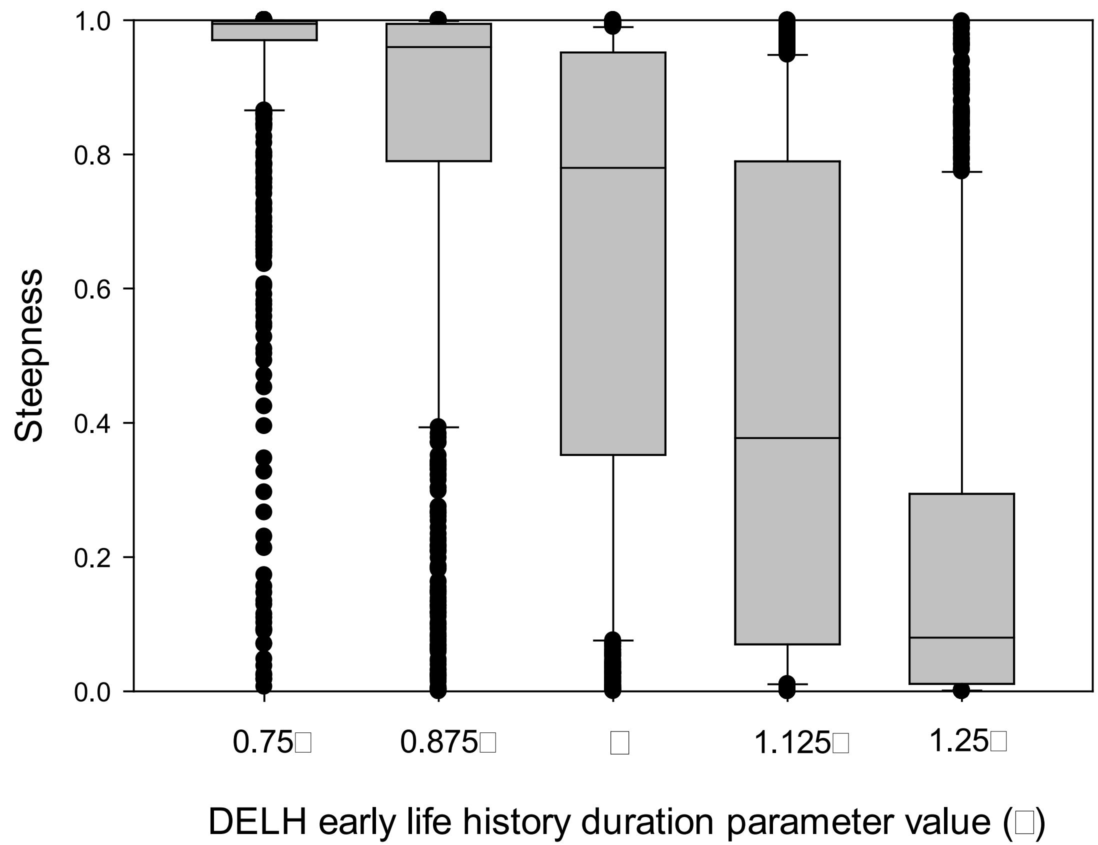
Sensitivity of Steepness to Asymptotic Length



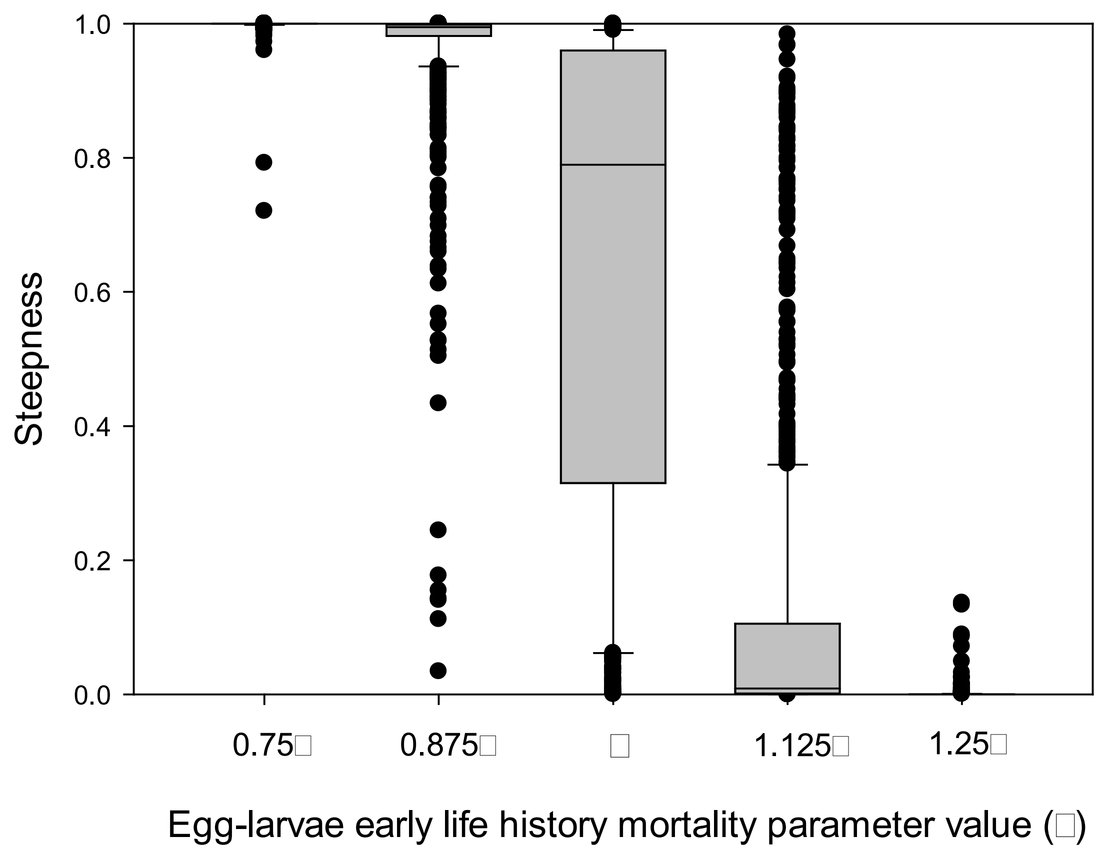
Sensitivity of Steepness to Adult Natural Mortality Rate (M)



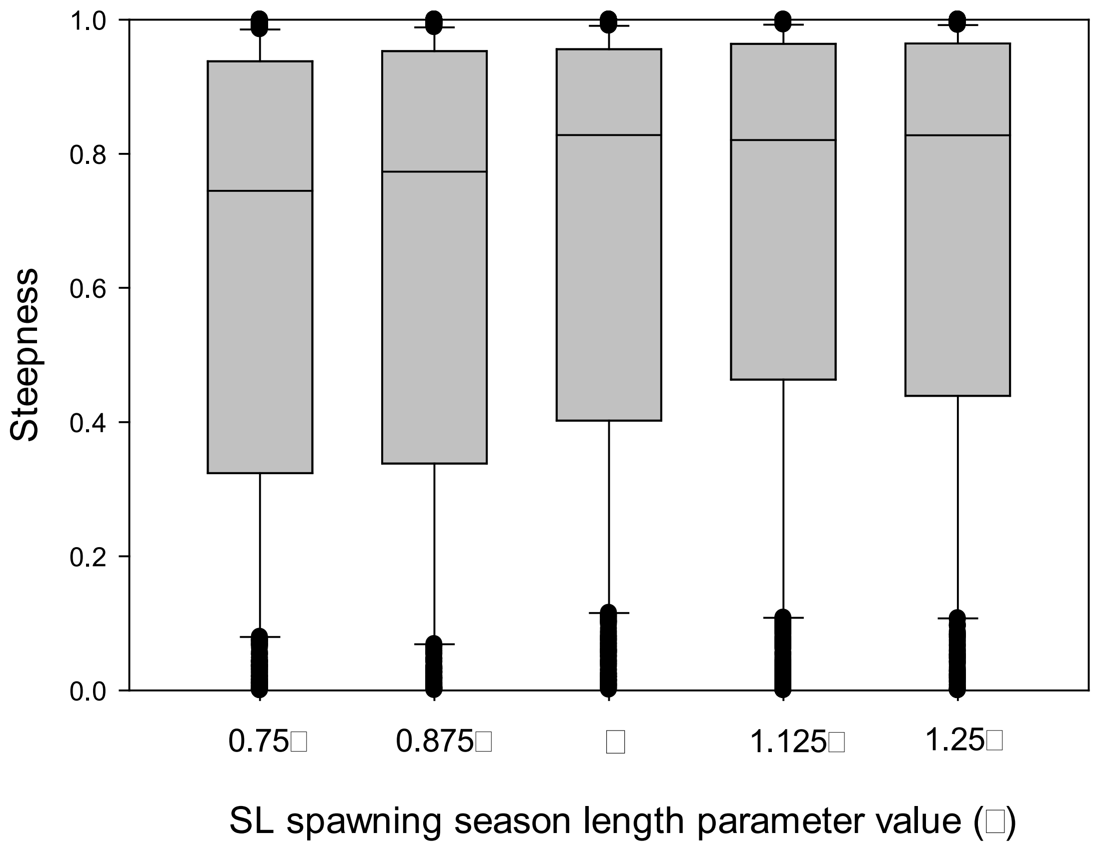
Sensitivity of Steepness to Early Life History Stage Duration



Sensitivity of Steepness to Egg-Larval Mortality Slope



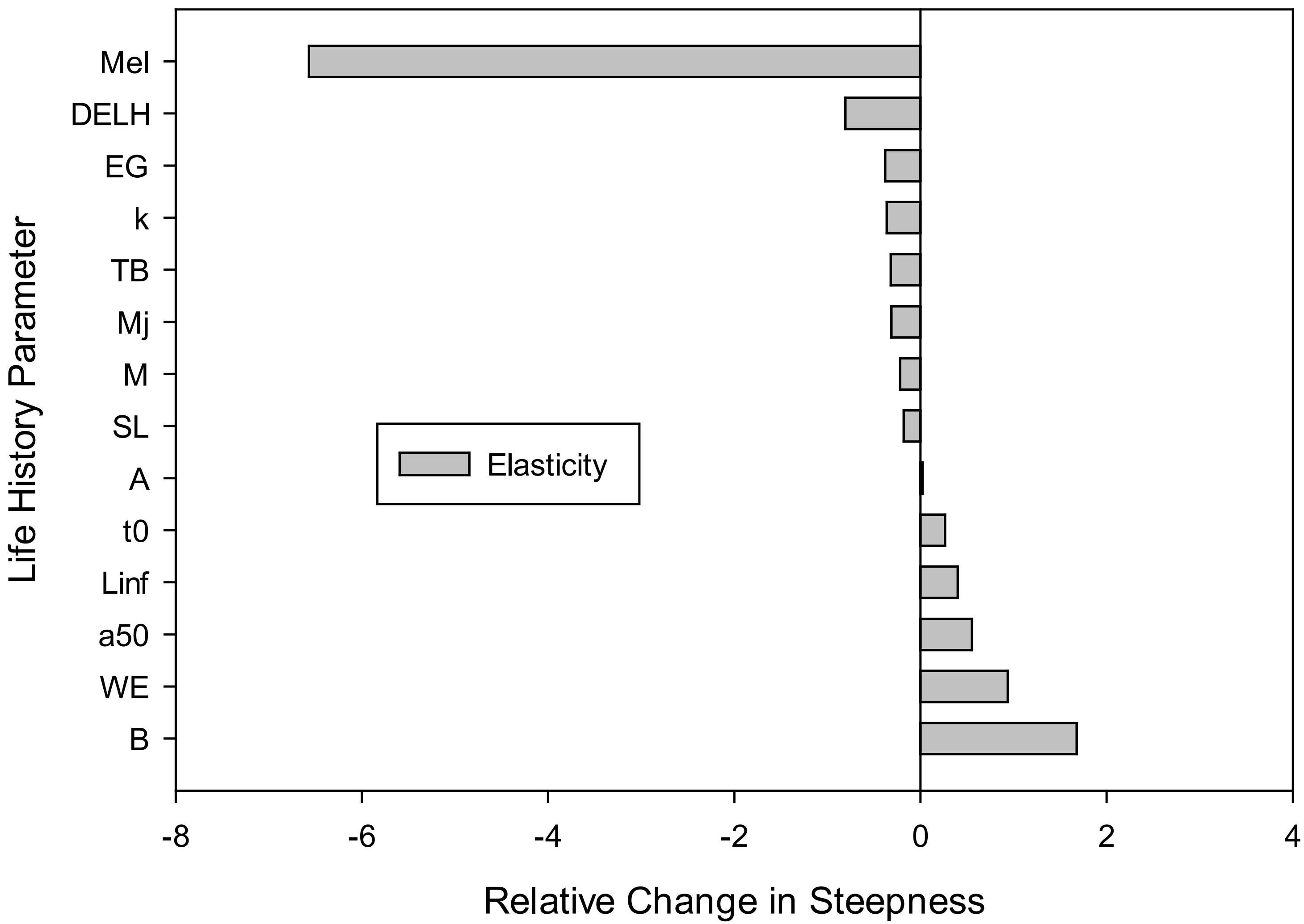
Sensitivity of Steepness to Spawning Season Duration



Characterizing Parameter Sensitivity: Elasticity of Steepness (h) to Parameters θ_k

$$U_h(\theta_k) = \frac{\partial h}{\partial \theta_k}(\underline{\theta}) \cdot \left(\frac{h}{\theta_k}\right)^{-1}$$

Comparing Elasticities of Life History Parameters

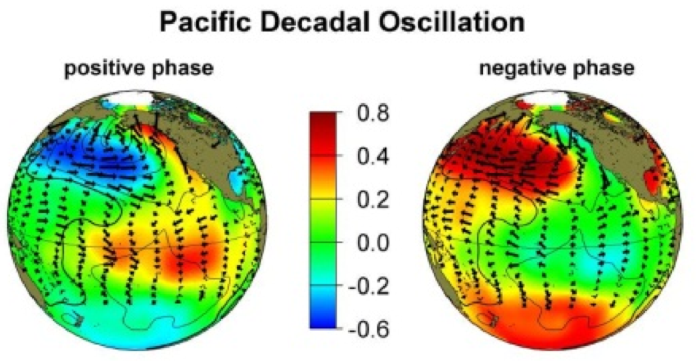


Conclusions and Future Research

- Given an age-structured model for cohort dynamics with stochastic variation, one can determine an associated distribution of steepness h
- As a result, choosing an arbitrary steepness value will produce model misspecification in an assessment

Conclusions and Future Research

- Striped marlin steepness is likely relatively high, but has a broad range of uncertainty that should be reflected in the stock assessment
- Steepness is sensitive to reproductive ecology and more work is needed:
  - ✓ Extend standard model with environmental linkage
  - ✓ Focus on ELH data collection and metaanalysis
  - ✓ Create world-wide ELH information database



Thanks and Mahalo ~!